SEMICONDUCTOR POWER DEVICES WITH ALTERNATING CONDUCTIVITY TYPE HIGH-VOLTAGE BREAKDOWN REGIONS

TECHNICAL FIELD

This invention relates to the semiconductor power devices.

BACKGROUND OF THE INVENTION

It is well-known that in the conventional semiconductor power devices, the reverse voltage applied across the n^+-region(s) and p^+-region(s) is sustained by a lightly doped semiconductor layer, called hereafter as voltage sustaining layer. For high voltage power devices, the on-resistance (or the on-voltage) is also dominantly determined by the voltage sustaining layer. The breakdown voltage mainly depends on the doping concentration and the thickness of the layer. The lower the concentration is and/or the larger the thickness is, the higher the breakdown voltage is, but the larger also the on-resistance (or the on-voltage) is. One of the most important problems of many power devices, especially of the majority devices like VVMOS, VDMOS and RMOS, is to get both high breakdown voltage and low on-resistance. For example, in the most advanced power MOSFET, RMOS(or UMOS), shown schematically in FIG. 1, the voltage sustaining layer is an n^+-epi-layer, the theoretical limit of the on-resistance in unit area Ron is $Ron=7.4\times10^{-9}V_B^{2.5}[\Omega.cm^2]$, where V_B is the breakdown voltage of the device. For references of the relation between Ron and V_B see: [1] C. F. Wheately. G. M. Dolny. Solid-State Technology, November 1985.pp 121–128; [2] C.Hu. IEEE Trans. Electron Devices, Vol. ED-26, NO. 3.pp. 243–246(1979); [3] D. Ueda, H. Takagi, G. Hano. IEEE Trans. Electron Devices, Vol. ED-34.pp 926–930 (1987); (4) H. R. Chang. R. D. Black et al. IEEE Trans. Electron Devices, Vol. ED-34, pp. 2329–2333 (1987). Also, see a U.S. patent—[5] Goodman et al. U.S. Pat. No. 4,366,495, Dec. 23, 1982, where improvement has been made to reduce the practical on-resistance of the VDMOS, however, the devices disclosed in Goodman et al. retain the relation between Ron and V_B. This relation has been an obstacle for making high performance power devices. Moreover. Ron stated above refers to the conduction area of the voltage sustaining layer, but practically, there exists always some areas which do not contribute very much to the conduction. The examples of such areas are: the area under the source-body in a vertical MOSFET; the area under the base contact of the bipolar transistors.

SUMMARY OF THE INVENTION

In this invention, a new structure of the voltage sustaining layer is proposed by the inventor. This new type of layer is called composite buffer layer, or shortly, CB-layer. The active region of the power devices is made just above this layer. Then, the restriction of Ron versus V_B for the power devices is remarkably released and the new power devices have much better performance in this respect, i.e. in the respect of the on-voltage and the breakdown voltage. This is due to the fact that the new devices have a new limitation relation between Ron and V_B which is based upon a new principle.

The CB-layer proposed in this invention contains two kinds of regions with opposite types of conduction, i.e., the n-regions and the p-regions. These two regions of different conduction types are alternately arranged, viewed from any cross-section parallel to the interface between the CB-layer itself and the n^+-region, whereas the voltage sustaining layer hitherto used contains only one uniform region with a single type of conduction of semiconductor (n-region, or p-region, or i-region) in the same sectional view. Each n-region and each p-region of the CB-layer has two surfaces contacted respectively with the n^+-region and the p^+-region. Except these two surfaces of each region, every p-region is surrounded by the neighbor n-regions and vice versa, as shown in FIG. 2. Thus, when the CB-layer is depleted, the n-regions and the p-regions contribute charges with opposite signs, and the fields induced by them cancel each other out for the most part. The doping concentrations of the n-regions and the p-regions, therefore, can be much higher than that in the conventional voltage sustaining layer. And, the on-resistance of the former is much lower than that of the latter.

The way of the arrangement of the p-regions and the n-regions in the CB-layer is called the layout. The layout may be any one of the following: 1) Interdigital layout: In the sectional view of the CB-layer, all the n-regions and the p-regions are stripe. The n-region and p-region are alternately arranged; 2) Layouts with hexagonal cell, or square cell, or rectangular cell, or triangular cell. In the sectional view of the CB-layer, hexagonal (or square, or rectangular, or triangular) cells are close-packed. All the n(or p)-regions are circle (or square, or rectangle. or triangle) and located at the middle of the cells, and each cell has one and only one such a region. The rest of the area of each cell is filled with p(or n)-region; 3) Layouts with mosaic structure. In the cross-section of the CB-layer, all the p-regions and the n-regions are square (or triangle, or hexagon), and the n-region and the p-region are alternately arranged. FIG. 3 shows schematically each example of the three kinds of layouts mentioned above. In all layouts, the smaller the size (or the width, or the radius) of each p-region as well as each n-region is, the lower the on-resistance in unit area is. In addition, in order to get the lowest on-resistance in unit area, the area of each p-region should be equal or almost equal to the area of each n-region.

The design guidelines for the CB-layer proposed by the inventor is as follows. If the breakdown voltage is required to be V_B [V], then the thickness of the CB-layer should be $0.024\ V_B^{1.2}[\mu m]$. For interdigital layout, if each n-region and each p-region have the same width $b[\mu m]$ then the effective donor concentration of the n-regions and the effective acceptor concentration of the p-regions are both equal to $7.2\times10^{16}V_B^{-0.2}/b[cm^{-3}]$. For the layouts with square mosaic structure, if the width of each region is $b[\mu m]$, then the effective donor concentration of the n-regions as well as the effective acceptor concentration of the p-regions are both equal to $9.1\times10^{16}V_B^{-0.2}/b[cm^{-3}]$. For other layouts, if each n-region and each p-region have the same area A $[\mu m^2]$, then the effective donor concentration as well as the effective acceptor concentration are both equal to $8.7\times10^{16}V_B^{-0.2}\sqrt{A}[cm^{-3}]$.

The above design guidelines for the concentrations proposed by the inventor are for the lowest on-resistance in unit area-Ron. The value of Ron is then $Ron=6\times10^{-7}bV_B^{1.3}[\Omega.cm^2]$ for interdigital layout, and $Ron=4.7\times10^{-7}bV_B^{1.3}[\Omega.cm^2]$ for layout with